Analysis and Modeling of Microwave Scattering Data

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LONG-TERM GOALS

Our long-range objective is to detect and understand microwave sea surface signatures produced by a variety of natural and man-made causes.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are to develop and test the multiscale model of microwave backscatter from the ocean to enhance its range of applicability, especially at high incidence angles and during rain.

APPROACH

Our approach is to develop spectral models of short waves on the sea surface for use in the multiscale model that will include effects of bound waves and rain drops. These models are being developed by analyzing previous experimental results, obtained both by us and by others, studying previous theoretical work, conducting new experiments on the Cowlitz River near Castle Rock, WA, and attempting to incorporate the results into the framework of the multiscale model.

WORK COMPLETED

We have analyzed data from several previous experiments during the course of FY 2003. Collaborating with Mark Donelan, we continue to analyze data on threshold effects in wind wave generation collected in the CCIW wind wave tank in 1996 as well data on short wave modulation by long waves collected in the University of Miami wind wave tank in 2001. We are using data we collected onboard the R/V Ron Brown in 1999 in our rain effects modeling and have collected additional data from the Cowlitz River both during rainfall and during clear periods. Finally, this year, we have reanalyzed the old sea-surface slope data of Cox and Munk, 1954, in light of our bound-wave ideas.

The continuing analysis of the CCIW data set is in response to the reviews of the paper we submitted to the Journal of Physical Oceanography. In order to respond to these reviews, it was necessary for us to collect additional data using the laser slope gauge at longer fetches. These data have now been collected and are being analyzed. The Cowlitz River measurements have been conducted to obtain

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additional data on rain effects on backscatter at light rain rates and to observe backscatter in the absence of rain and bound waves.

Three papers have been accepted or published this year as a result of this research. Papers published this year include the initial paper on the multiscale scattering model (Plant, 2002) and our rain work from the Ron Brown (Contreras, et al., 2003). A paper showing that Cox and Munk's (1954) data can be fit by a bound wave/free wave model has been accepted by the Journal of Geophysical Research (Plant, 2003). Complete lists of our publications and summaries of our results can be found on the following web site: staff@washington.edu/plant/.

RESULTS

a. Sea-Surface Slopes

We realized this year that the bound wave/free wave model that we have developed to explain microwave backscatter from the ocean and in wind wave tanks could also explain the non-Gaussian sea-surface slope probability density functions (PDFs) obtained by Cox and Munk (1954) from sun glitter patterns. The standard method of fitting these PDFs is to fit them to a Gram-Charlier series given by

$$P(s) = G(s) [1 + (c_3/6)H_3 + (c_4/24)H_4]$$

where s is sea-surface slope, P(s) is the PDF, H_n are Hermite polynomials of order n, and c3 and c4 are coefficients related to skewness and kurtosis, respectively. G(s) is a Gaussian PDF given by

$$G(s) = \sigma^{-1} (2\pi)^{-0.5} \exp\{-(s-\langle s\rangle)^2/\sigma^2\}$$

Where σ is the standard deviation of s and $\langle s\rangle$ is its mean. This series can be derived by assuming that sea-surface waves are weakly non-linear (Longuet-Higgins, 1963).

Our bound wave/free wave approach does not require that the waves be weakly nonlinear but allows for highly non-linear processes such as breaking and "crumpling". To fit PDF to this model, we employ Bayes' Theorem in the form

$$P_{fb}(s) = P_f\, P(s|f) + P\mathbf{b}\, P(s|b)$$

where Pf and Pb are the probabilities of finding free and bound waves on the surface, P(s|f) is the probability of slope s given that it is associated with a free wave, and P(s|b) is the probability of slope s given that it is associated with a bound wave. We assumed that these conditional probabilities were Gaussian and minimize the cost function, C, given by

$$C = 100[P(s)-Pfb]^2 + [c4 - c4cm]^2$$

To fit Cox and Munk's distributions. The result is shown in Figure 1.

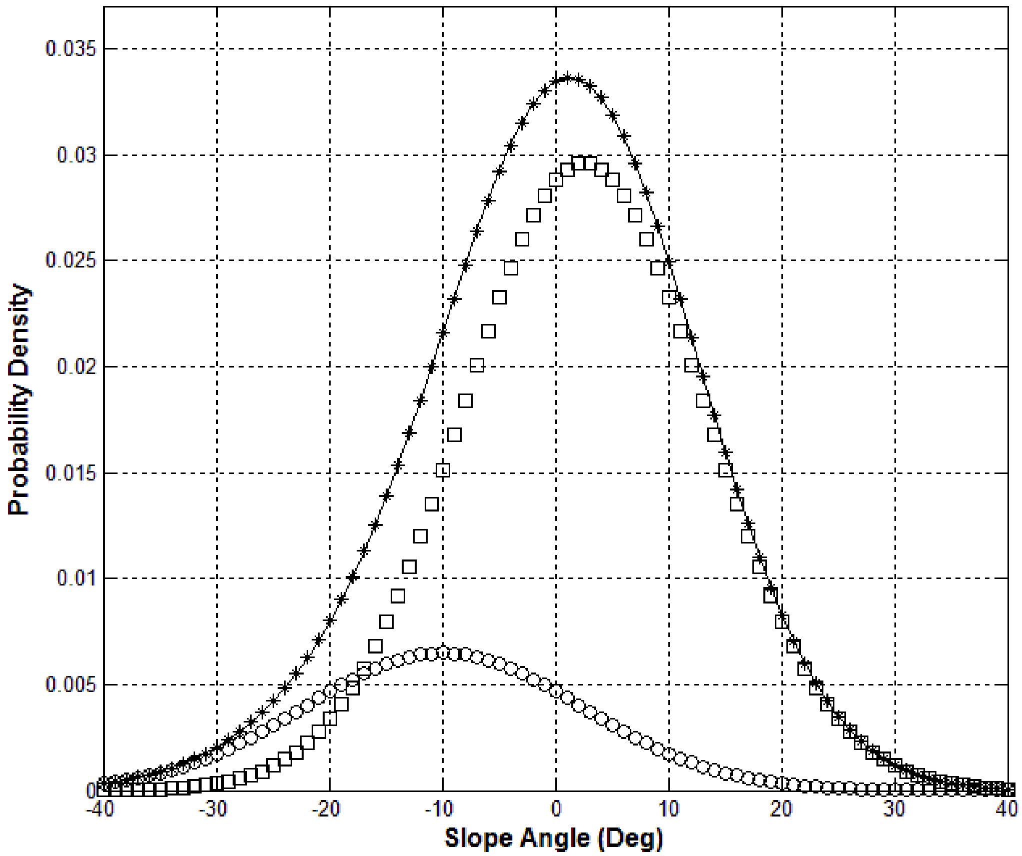

Figure 1. The plus signs show P_{fb} obtiained from the weighted sum of a bound-wave Gaussian PDF (circles) and a free-wave Gaussian PDF (squares). The line is the Gram-Charlier fit to the data of Cox and Munk (1954) at a wind speed of 10.2 m/s.

Parameters necessary to produce this fit matched those measured in a wind wave tank rather well except for the variances, which were larger on the ocean. The probability of finding bound waves (~40%) is much larger than the probability of whitecapping on the ocean (~1%), which implies that a large fraction of bound waves are microbreakers or parasitic capillaries. More details can be found in Plant (2003).

b. Scattering Without Rain or Bound Waves

Our measurements on the Cowlitz River have shown that, in the absence bound waves, microwave backscatter from wind-roughened water surfaces is well described by Bragg scattering, with a minimum of composite-surface effects due to long waves found on the river. This is well indicated by the polarization ratio which is very close to that predicted by Bragg scattering theory. This is shown in Figure 2

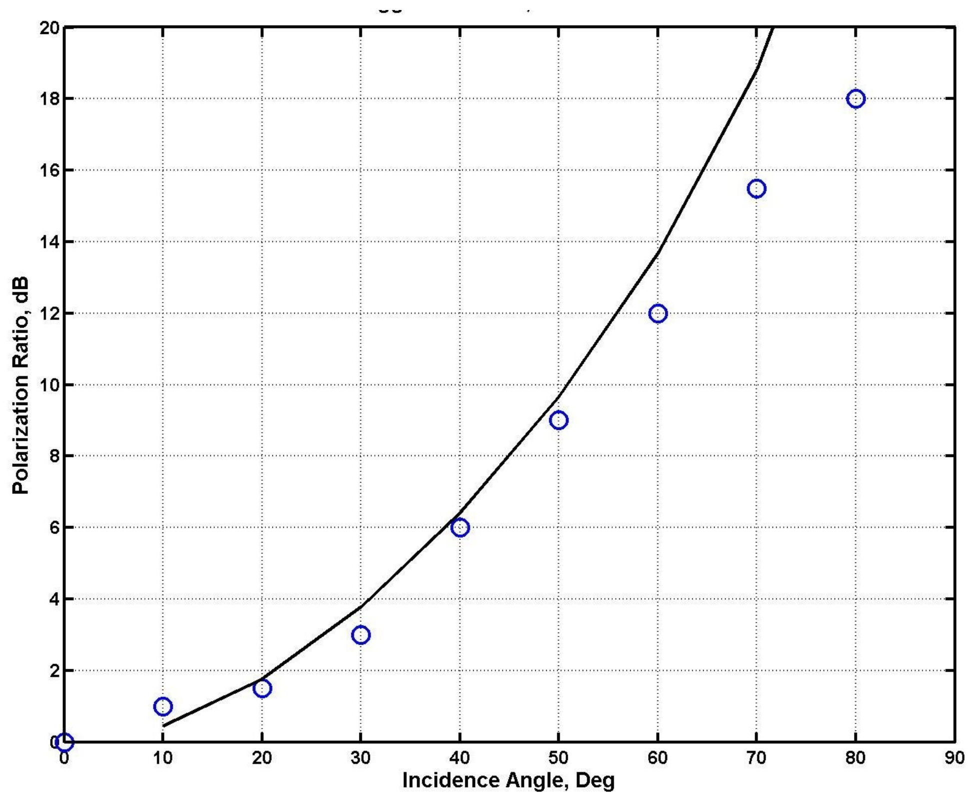

Figure 2. Polarization Ratios, $\sigma o(VV)$-$\sigma o(HH)$ in dB, measured on the Cowlitz River (circles) and predicted by Bragg Scattering theory (curve). Measurements were made at Ku-band and are averaged over all wind speeds and directions.

c. Rain Effects at Low Rain Rates

We have been attempting to include effects of rain in the multiscale model by modeling the effect of rain of the spectrum of short surface waves. Two primary effects of rain on the water surface are considered: ring wave generation and turbulent damping of short gravity waves. These phenomena alter the background wind wave spectrum. The wind wave spectrum being used is that of Kudryavtsev et al. (1999). This model relies on energy balances to determine the form of the spectrum in different wave number regions, and, therefore, damping by rain-induced turbulence can be added as an eddy viscosity. Ring waves serve to enhance the wave number spectrum. In this treatment, ring waves are simply added to the wind wave spectra mentioned above. Figure 4 is an example of the modeled surface height field. From this the surface height spectrum is calculated. This method extends to higher wave numbers than the model of Bliven et al. (1997).

Results to date at high rain rates reproduce SAR observations reported by Melsheimer et al., 1998. These observations show that rain cells are more easily observed in SAR images at X-band than at C-band and that they suppress return at L-band in contrast to the enhancement at the other two frequencies. Figure 3 shows that at incidence angles above about 30^{o}, this is precisely what the multiscale model with rain effects predicts.

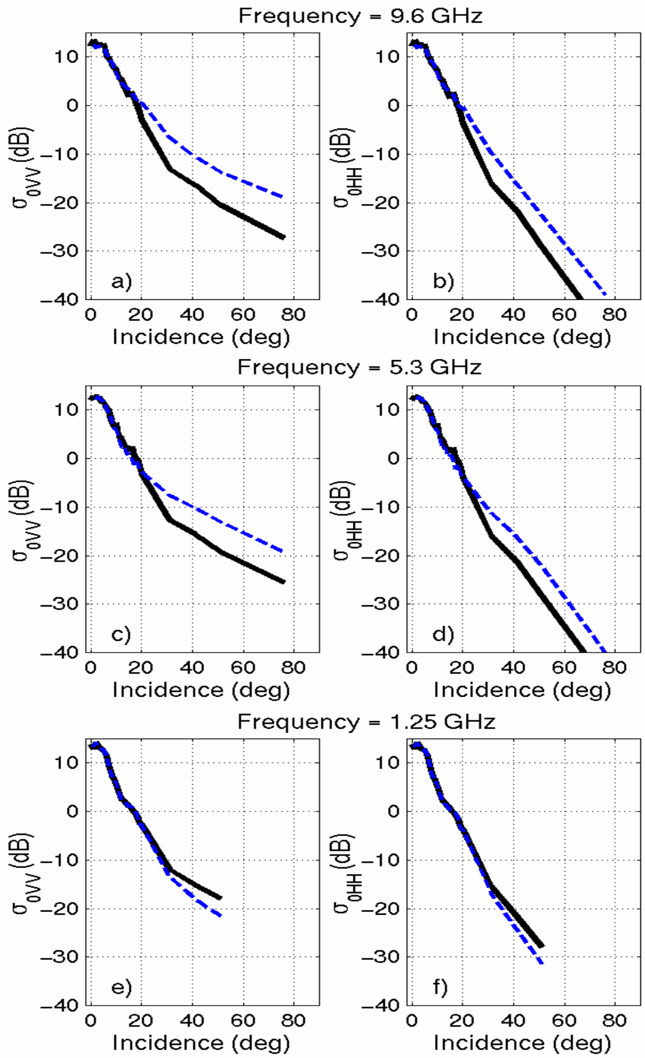

Figure 3. Cross sections predicted by the multiscale scattering model for no rain (solid) and a rain rate of 41.5 mm hr^{-1} (dashed). The wind speed is 5 m s^{-1}: X band a) VV and b) HH polarization; C band c) VV and d) HH polarization; and L band e) VV and f) HH polarization.

IMPACT/APPLICATION

Our results shed new light on microwave backscattering from the ocean under a variety of environmental and system conditions. Thus they are applicable to any microwave radar that senses the ocean surface. In particular, they promise to aid our understanding of the imagery of signatures of surface and subsurface vehicles, especially in the higher incidence angle region where bound waves become most important.

TRANSITIONS

The results of this project have not yet been transitioned for operational use.

RELATED PROJECTS

This project is closely related to Andy Jessup's ONR project; FAIRS IR and microwave data are being analyzed jointly with Jessup.

This project is directly related to NASA scatterometers, such as the NSCAT, QuikScat, and SeaWinds. Data collected under this funding have been used in an NSCAT-related project to attempt to develop better model functions and retrieval methods for scatterometers at low wind speeds. Further, the multiscale model is now being used in a NASA study of a physically based model function.

Finally, this project has many parallels with a Navy program to investigate the microwave signatures produced by submarines. The basic understanding of microwave scattering, especially at high incidence angles, produced in this project furthers these attempts to detect submarines.

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